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Roadside Slope Revegetation

past and current practice on the national forests

U.S. DEPARTMENT of AGRICULTURE FOREST SERVICE
EQUIPMENT DEVELOPMENT CENTER SAN DIMAS, CALIFORNIA

Equipment Development and Test Report 7700-8

ROADSIDE SLOPE REVEGETATION

Past and Current Practice on the National Forests

by

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ABSTRACT

Effective revegetation is a primary method of protecting roadside slopes from erosion. Information on current practices and equipment use was gathered from 25 National Forests and from other sources. In seedbed preparation, seeding, fertilizing, mulching, etc., a variety of methods and equipment is used, depending primarily on conditions in specific locations. A review of earlier and current literature yields suggestions for possible improvements in techniques. New equipment is needed, and suggested equipment for scarification, planting, and seeding of steep slopes is sketched.

KEY WORDS: Roadside Landscaping, Roadside Slope Revegetation, Slope Stabilization.

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A report on ED&T Project No. 2156 - Equipment for Slope Revegetation - sponsored by the Division of Engineering.

INTRODUCTION

The effects of roadbuilding on the esthetic and watershed values of forest land have become a matter of increasing concern to the public. Prominent among objections made to roads through the forests, whether these are built for timber access or for recreational purposes, is the presence of relatively steep roadside slopes showing little sign of revegetation, and frequently showing active erosion. The value of such revegetation in reducing soil erosion and stream and lake siltation has long been recognized by the Forest Service and other agencies, and much work has been done during the past 40 years.

In 1972, approximately 11,000 acres of National Forest road slopes were revegetated at a cost of about $4.5 million. The importance of this work in actual savings of money is evident from the following analysis: Effective slope revegetation can reduce soil losses from road slopes as much as 150 tons (or about 100 cu yd) per acre per year. An estimated $1 per cu yd in road maintenance funds is required to remove the soil from the road ditches and repair gullies in the fill slopes. The reduction in soil loss achieved by revegetation would mean an annual savings of $1.1 million per year. In many areas, 6 years are required to establish native vegetation by natural means. The total saving, when the initial cost of $4.5 million is compared to the $6.6 million of road maintenance funds otherwise spent in 6 years, would be $2.1 million. Thus the benefit/cost ratio of successful roadside slope revegetation, $6.6/ $4.5, is 1.47 to 1.

In view of the high value of revegetation, it seems worthwhile to expand our efforts in this area. It is essential, however, to assure that revegetation will be effective. Results of some projects have been discouraging. There is need for a complete study of revegetation procedures on roadside slopes, with the aim of providing alternate solutions for recurring problems. Some techniques successful in the past have been abandoned because they require hand labor. Could improved equipment help us to revive some of these techniques with good effect? What equipment is currently available? Could other improvements allow us to use this equipment under a wider variety of conditions?

To answer some of these questions, a study of the state-of-the-art of roadside slope revegetation was undertaken in 1971. Although no exhaustive coverage of either field operations or literature on roadside revegetation was attempted, a variety of sources was consulted, giving a broad view of the subject. No definite conclusions as to the success of specific techniques, equipment, or materials were made, because conditions of each operation observed varied widely. This report serves primarily to indicate the methods and equipment in current use, against a background of earlier approaches to the problems encountered in roadside revegetation. Several ideas for possible improvements are also suggested. Further studies will be required to develop new equipment and to evaluate the results of the various techniques now in use.

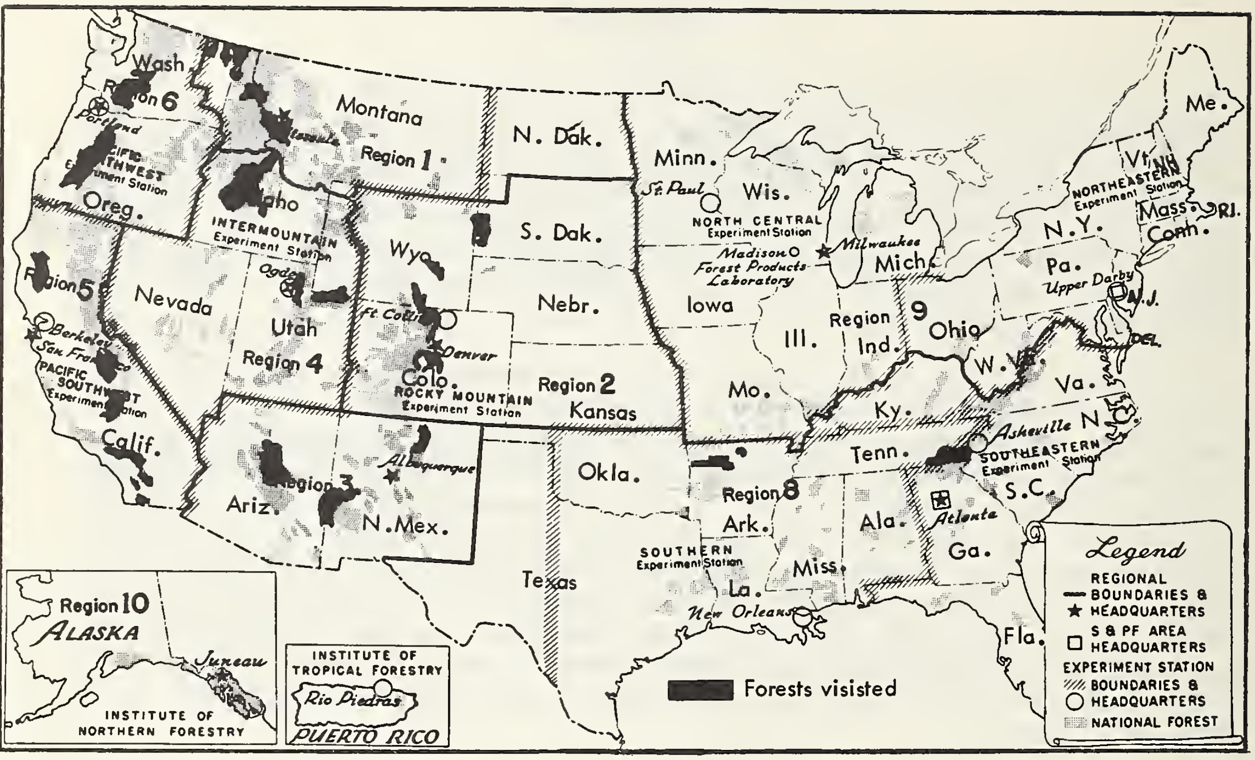


Figure 1. Forests visited during the survey of roadside slope revegetation practices.

For practical reasons, emphasis in this study was on forest practice in the western Regions, although several Forests in other parts of the country were visited (fig. 1).

Besides the eight Regions and 25 National Forests visited, two Forest and Range Experiment Stations (Intermountain and Pacific Southwest) were included in the survey. Also visits were made to Forest Service nurseries at Coeur d'Alene and Boise, Idaho. Interviews were also held with representatives of the California Division of Highways; the University of California, Davis; and the University of Montana. Five different pieces of slope revegetation equipment were observed in operation. Much of the information on equipment use was obtained through interviews with Forest personnel and visits to previously revegetated sites.

EARLY WORK ON SLOPE REVEGETATION

A review of the literature uncovers several works of the late 1930's which bring together observations and recommendations on revegetation of roadside slopes. Much of the material in these reports is valuable and will be summarized here and in later sections of this paper.

In his report, "Erosion Control on Mountain Roads," Kraebel (3) commented, "No sooner is a new road constructed than the forces of nature are at work to destroy it."

That is, wind, water, cold, heat, and the constant pull of gravity tear down fills, round off square edges of cut banks and road shoulders, and break up road surfaces. The wear on the roads by traffic is small compared to that of the forces of nature. Of these, water has the greatest impact.

Destructive forces can work very rapidly on mountain roads where areas of erodible fill slopes are not only large, but are also often exposed to concentrated runoff from the impervious road surface. The damage below a storm-gullied road is often greater than the damage to the road. The road can usually be repaired easily, but stream beds cannot.

The value of vegetation and the necessity for preventing its destruction during road-building were recognized in handbooks issued in 1937 and 1940 by the Forest Service Division of Engineering (6, 7). The authors emphasize that vegetation on cut or fill slopes that approach an unaltered nature in appearance increase the attractiveness of the road and at the same time reduces erosion losses. It is better to preserve desirable trees, shrubs, vines, sod, stones, and topsoil along the way than to replace them.

The importance of improved practices in preventing erosion and the loss of vegetation is a frequent theme. Kraebel (3) discussed some of these preventive and control measures. He points out that ideal erosion prevention cannot be obtained. Wider, straighter, and faster roads are demanded; whereas from the erosion standpoint they should be narrower, steeper, and more curving. Some improvement can be made, however, through these preventive measures:

New criteria of location. The well-built road should have in some degree the appearance of having been fitted into the landscape rather than chopped and blasted out of it.

More rational alignment. Long tangents should be traded for careful efforts to leave nature undisturbed by using more natural curvature, so that less volume of rock and earth is loosened.

Greater use of retaining walls. Retaining walls and cribbing are valuable to support roads in areas where fill slopes are less steep than the natural slopes. Although initial cost is higher than full-bench cutting, the wall or crib lessens the disturbance and decreases erosion and maintenance costs.

Controlled placement of excess soil.

Greater use of tunnels and bridges.

Improved drainage practice. Control measures on existing roads include drainage improvement to avoid such problems as culverts emptying at improper points; outfall not protected against undercutting; drainage outlets from road surface too few, or not properly spaced; drainage structures too small for high-intensity storms; and blocking of drainage by slides in through cuts.

> "The method of out-slope construction, in which the entire road is given a slight pitch toward the outer shoulder to permit continuous run-off laterally from the surface, does not appear well adapted to [certain areas]. Shoulders settle and wear rapidly during heavy rains. Despite all efforts to build and maintain uniform outward slopes, water nevertheless accumulates and runs down the axis of the road to some obstruction or slight depression where it pours out with sufficient force to cut a troublesome gully." (p. 10)

Abandoned roads should be properly drained or completely eradicated and planted.

In the 1937 handbook (7), we find that initial attempts to control erosion on fill slopes were conducted upon fills constructed 1 or 2 years previously. To refill and obliterate gullies that developed in these 2 years was costly.

> "Experiments indicate that erosion control can be economically carried out during roadway construction; that slope erosion can be materially reduced and the formation of deep gullies on fill slopes entirely prevented when fills are layered."

To this, the 1940 handbook (6, p. 504-506) added that erosion control through improved construction practices is an important second step before success may be obtained in revegetating road slopes. Among elements of improved construction emphasized is avoidance of stage construction. Going back each year and disturbing road slopes to obtain better road geometry and slope stability is a poor practice when erosion control is mandatory. Other measures cited are use of retaining walls, proper disposal of waste soil and debris, consolidation of fills, blasting control, conservation of top soil, avoidance of landslide areas, drainage control, provision of stable surfacing, and avoidance of damage to vegetation in road maintenance.

The comments of these earlier writers on specific methods of revegetation will be given, as appropriate, in later sections of this report. Of special interest, however, is the work of Gustaf Juhren, forester and silviculturist on the Angeles National Forest. In the late 1930's he was detailed to supervise emergency work to stabilize slopes on the Cleveland National Forest. Juhren relied extensively on Kraebel's work, which had been published shortly before, to accomplish this project. He put Kraebel's principles into operation, observing results from 1936 to 1953, and reporting on them. 1/

1/ Juhren, Gustaf. Lake Wohlford erosion control project, 1940; Erosion control on Palomar Mountain Observatory Road, 1946; Supplement to reports on Palomar Mountain and Lake Wohlford Roads erosion control projects, 1953. Unpublished reports on file at Angeles National Forest, USDA Forest Serv., Pasadena, Calif.

AN EARLY REVEGETATION PROJECT

Juhren's reports 2/ cover road slope revegetation work accomplished on Palomar Mountain Observatory Road in 1937 and Lake Wohlford Road in 1939. Examinations of the roads were made up to 18 years after the slopes were planted. Planting of vegetation on the slopes of Palomar Mountain Observatory Road in 1937 (fig. 2) was done in desperation to save the newly constructed road embankments from annual winter storms.

The project was started by the San Diego County Road Department in 1933, but each summer's road construction was virtually eliminated by the following winter's storms.

The slopes had to be stabilized before progress could be made. The general method employed consisted of contour wattling, use of long wheat straw between rows, seeding of rye, and the planting of willows, baccharis, and other shrubs and trees.

Thousands of trees and shrubs were donated by local nurseries. Improved drainage techniques also played an important role. In 1938, after heavy rains, the only slopes which did not erode away were those protected by erosion control measures. After this experience, similar measures were used on all the slopes. These amounted to 22 acres, planted at the expense of 200 to 500 man-days per acre by W.P.A. and prison labor crews.

The following shrubs and trees were planted, all on south exposures, and were still in existence when the 1946 examination was made:

Elevation (ft)	Plant	Condition
3,320	Arizona cypress (*Cupressus arizonica*)	Excellent
3,320	Mahogany sumac (*Rhus intergrifolia*)	Fair
3,320	Monterey pine (*Pinus radiata*)	Good
3,320	Sugar sumac (*Rhus ovata*)	Fair
3,320 - 4,700	Nevin hollygrape (*Berberii nevinii*)	Fair
3,320 - 5,200	Mulefat (*Baccharis viminea*)	Excellent
5,200	Black locust (*Robinia pseudocacia*)	Excellent
5,200	Senecio (*Senecio salignus*)	Good
5,200	Mountain mahogany (*Cerocarpus betuloides*)	Good
5,200	Palo blanco (*Foresteria neomexicana*)	Good
5,200	Willow (*Salix* spp.)	Good
5,200	Cedar (*Libocedrus decurrens*)	Good

2/ *Op. cit.*

Station 82 **A** 10/5/39
Construction of dry rock toe wall or riprap at toe of slope.

Station 82 **B** 10/9/39
Placing of brush-mat on top of toe wall.

Station 82 **C** 10/10/39
Smoothing of slope.

Station 82 **D** 10/11/39
Slope area, 0.80 acre. Slope %, 80. Slope length 400 ft. Slope smoothed and ready for wattling.

Station 82 **E** 4/15/41

Station 82 **F** 4/10/46
Slope well stabilized. Dense vegetation of baccharis and native shrubs.

Figure 2. Revegetation work reported by Juhren on the slopes of Palomar Mountain Observatory Road (this page) and Lake Wohlford Road, south grade (next page) is shown in these successive views, reproduced from the original reports.

Station 94 **G** 6/10/38
Construction of dry rock retaining wall.

Station 94 **H** 7/5/38
Rock wall completed. Elevation 3320. South exposure. Area, 0.25 acre. Slope refilled December 1938. Wattled and planted with baccharis, cuttings, trees and shrubs, January 1939.

Rainfall	1936-1937	-	53 inches
"	1937-1938	-	37 inches
"	1938-1939	-	32 inches

Station 94 **I** 8/15/39
Fill slope wattled and planted.

Station 94 **J** 8/26/46
Note cypress on sides of slope.

Station 94 **K** 11/52
Fill slope wattled and planted. Note cypress on sides of slope.

Figure 2. Continued.

Juhren observed that topsoil appeared to have a significant advantageous effect on plant growth. Also, he noted from subsequent inspection that, unhappily, side casting of material from road maintenance had destroyed much of the planted and natural vegetation.

Revegetation work on Lake Wohlford Road in 1939 (fig. 2) was done by a 20- to 30-man W.P.A. labor crew. The stabilization of fill slopes consisted of contour wattling and planting of baccharis and native plants. Twelve-hundred trees and shrubs were provided for the project. One slope, 400-ft long and very steep, was covered with wheat straw 4-in. thick at a rate of 5 tons per acre. The following species were also used on the project: golden bush (Bricameria parishii and B. pinifolia), Coulter pine (Pinus coulteri), knobcone pine (Pinus attenuata), Catalina Island buckwheat (Eriogonum arborescens), monkey flower (diplacus), sumac, ceanothus, baccharis, Chinese elm, and locust.

In November 1972 the roads were reexamined. On Palomar Mountain Road the fill slopes were well stabilized. On some slopes, however, overcasting of slide material had killed plants over a large enough area to threaten the future stability of the slopes. In clearing brush from the shoulders, cutting had been extended many feet down the slope. Good trees planted a sufficient distance from the road for unobstructed view had been removed. Of the original planting, the following species still remained: hollygrape, mahogany sumac, baccharis, Arizona cypress, and Monterey pine. In some areas Mulefat (Baccharis viminea) had died out and was replaced by voluntary growth of white sage (Salvia apiana), Wild oat (Avena fatua), and brome grasses such as rip-gut (Bromus rigidus), and red brome (B. rubens). Willow cuttings did very well.

On Lake Wohlford Road, plantings adjacent to drainage structures were excellent. The most successful plants were the Coulter pine, knobcone pine, Chinese elm, locust, Arizona cypress, redshank (Aderostoma sparsifolia) and saltbrush (Atriplex brewerii). Here the baccharis had practically disappeared and was replaced with annual grasses, monkey flower, laurel sumac, and ceanothus. These provided adequate cover to the slopes.

These projects represent a desperate attempt to control erosion on long, steep mountain slopes. Juhren's success in using the principles set forth by Kraebel suggests that we may also find them useful today.

REVEGETATION PRACTICE AND EQUIPMENT USE ON THE NATIONAL FORESTS

Survey Results

The survey of current practices in roadside slope revegetation covered 25 National Forests, as described earlier (fig. 1). From interviews and observations, information was gathered on methods and equipment and on the success of revegetation. Equipment used in the various stages of revegetation is listed and described in table 1. Information gathered on the practices used by each Forest is summarized in table 2, and table 3 gives the number and percent of Forests using some of the specific techniques.

Table 1. Equipment currently used in roadside slope revegetation

Stage of revegetation	Name of equipment	Description	Support equipment	Function
Seedbed preparation	Chain scarifier (clod buster)	Cable set with crossed spikes; weighted swivel at bottom end; cable hangs over bank	Tractor for drawing cable	Breaks up soil crust
	Sheepsfoot roller	Roller with rows of cylindrical projections. (Normally used for soil compaction on earth fills)	Crane or sideboom tractor for pulling roller up and down slopes	Breaks up soil crust and compacts slope
Seeding	Hydroseeder or hydromulcher	Truck-mounted tank with pump and nozzle	If needed: water tanker; flatbed trucks for mulch and fertilizer	Spreads seed, with or without fertilizer, mulch, etc., using water as a conveyance; range 250 ft
	Cyclone broadcast seeder	Seed container with hand crank to throw out seed	None	Spreads seed manually
	Fertiblast gun	Air nozzle	Air compressor; holding tank for seed and fertilizer; pickup truck	Spreads seed using compressed air as a conveyance; range 75 ft
	Rangeland drill and other commercial drills	Usually a two-wheeled implement including devices to make furrows in soil and cover seed applied through tubes	Tractor (towing vehicle)	Applies seed in rows and covers them with soil. Application rate of seeds may be closely adjusted. Depth at which seeds are put into soil may be closely adjusted
Mulching	Hydromulcher or hydroseeder	See above	See above	Applies mulch (wood cellulose products) with or without seeds, etc.
	Hay and straw mulchers	Large nozzle with blower, usually mounted on two wheels for towing. May have attachment to nozzle for spraying water or asphalt emulsion with mixture	Towing vehicle usually stakeside truck, with hay or straw on the bed for feeding the mulcher. Water trailer or asphalt emulsion trailer when needed	Spreads a mixture of hay or straw, seed, and fertilizer. Water may by applied to aid germination. Asphalt emulsion is applied to stick hay and straw particles together to prevent wind from blowing them off the slopes
	Straw compactor	Roller with yoke for towing. Prototypes were sheepsfoot roller with cylindrical studs removed and replaced by studs made of rectangular plates. Plates are designed to prevent pulling straw back out of slope	Side boom tractor or hydraulic crane for rolling up and down slopes	Pushes straw and seeds into the soil and compacts soil and mulch over seeds. Straw is pushed into soil to anchor it, thus reinforcing the soil
	Brush roller (conversion) 1/	Prototype roller similar to straw compactor but having studs mounted on concentric disks, allowing roller to flex over rock or uneven surfaces	See above	See above
	"Schmeiser (culti-pactor)"	A roller similar to a farm disk harrow, but wider and having lugs on the rings. Concentric rings follow the contour of the ground	Tractor	Used on contract project to mix seed, soil, straw and fertilizer

1/ Brush roller was developed by Charles A. Graham, USDA Forest Service Pacific Southwest Forest and Range Experiment Station, stationed at Fresno, Calif., in cooperation with the San Dimas Equipment Development Center.

Table 2. Methods and equipment used in roadside slope revegetation on 25 National Forests 1/

Notionol Forest and Stote	Seedbed preparotion	Seeding and planting		Promoting germination and growth		Work crew	Estimated success 3/
		Grosses (seeded) with mulch or odditive	Trees ond shrubs, seeded or planted	Mulching 2/	Rolling		
Angeles - Colif.	Sheepsfoot roller	Broodcast		Straw	Straw compactor and Culti-poctor	Contract	Good
	Sheepsfoot	Broadcast		Straw	Straw compoctor and Culti-pactor	Contract	Good
	Sheepsfoot	With mulch		Hydromulch ond Verdyol complex		Contract	Fair
	Sheepsfoot	Hydromulcher with Soil Seal				Contract	Poor
	Sheepsfoot	With mulch		Strow	Strow compactor	Forest Service	Good
	Manual	With mulch	Brush wattling	Straw		Forest Service	Good
Apoche - Arizona, N. Mexico		With mulch		Hydromulch		Forest Service	Good
Block Hills - S. Dokota		With mulch		Hydromulch		Forest Service	Excellent
Boise - Idoho		Broadcast; with mulch	Native older plonted ond seeded	Hydromulch		Contract	Good
	Choin scorifier 4/	With mulch	Wattling	Strow	Sheepsfoot	Forest Service	Gross - good Alder - poor
Carson - N. Mexico	Top of cut slope ripped	Drill on upper part; with mulch on lower part	Native shrubs plonted	Hydromulch and excelsior		Forest Service	Excellent
	Slopes terraced	Hydroseeder		Excelsior mot		Forest Service	Excellent
Challis - Idoho		Broadcast 5/				Forest Service	Good
Cherokee - Tenn. 6/	Not required 7/	During construction; with mulch		Straw with SS-1 emulsion		Controct	Excellent
	Not required 7/	During construction; with mulch		Wood chips with mulcher		Contract	Poor
	Slopes serrated	With mulch		Straw		Controct	Excellent
Cleveland - Colif.	Sheepsfoot	With mulch		Straw		Contract	Good
	Sheepsfoot	With mulch		Hydromulch		Controct	Good
	None (cut slope)	With Aquotain				Contract	Excellent
Coconino - Arizona		With mulch		Hydromulch		Forest Service	Not determined
Colville - Wosh.			Native shrubs from Coeur 'Alene Nursery			Forest Service	Good
		Fertiblost gun				Forest Service	Good
Coeur 'Alene - Idaho		With mulch		Hydromulch		Controct	Excellent
		With mulch	Willow cuttings from nursery			Contract	Excellent
Gifford Pinchot - Wosh.		With mulch		Hay		Forest Service	Good
Medicine Bow - Wyo.	Broodcost seeded during construction	With mulch		Straw		Forest Service	Not determined

Table 2. (Continued)

Mendocino - Colif.		With mulch		Hydromulch		Controct	Good
Nantoholo - N.C.		With mulch		Strow		Controct	Excellent
Pike - Colo.		With mulch		Hydromulch		Forest Service	Foir
			Nursery stock			Forest Service	Not determined
Roosevelt - Colo.		With mulch		Hydromulch		Forest Service	Good
St. Joe - Idaho		With mulch		Hydromulch		Forest Service	Good
Salmon - Idaho	Broadcast					Forest Service	Not determined
San Bernordino - Colif.		Contour seeded				Forest Service	Foir
	Smoothed, wotered, rolled	With mulch		Straw	Studded roller	Controct	Good
	Smoothed, wotered, rolled	With Verdyol Super		Hydromulch		Controct	Excellent
	Smoothed, watered, rolled		Native shrubs seeded			Controct	Poor
Sequoia - Colif.		Broadcost				Forest Service	Good
Sierro - Calif.	Crust broken with roller	Broadcost		Straw (manually applied)	Brush roller (modified)	Forest Service	Not determined
Umpqua - Oregon		With mulch		Hay		Forest Service	Good
		Hydroseeder with Aquotain				Contract	Not determined
Wasatch - Utah		Hydroseeder		Wheatgrass, strow with SS-1 emulsion		Forest Service	Good
		Hydroseeder		Strow with SS-1 emulsion		Forest Service	Good
Willomette - Oregon		With mulch		Hay		Forest Service	Excellent

1/ Dato gathered from interviews during the period March 1971 - December 1972, except os noted.
2/ Straw and hay mulches were applied by machine unless noted. Various hydromulching machines were used.
3/ No evaluation or comparison of equipment, products, or Forest work is intended; project conditions voried widely ond no specific conclusions can be drawn from the subjective judgements reported.
4/ Informotion from 1963 report on file ot Boise Notionol Forest.
5/ Vegetation seeded was unpalotoble to cattle.
6/ All projects on Tennessee Forest Highway, Federol Highway Administrotion, District 15.
7/ Stoged revegetotion progrom ollowed seeding of fresh slopes.

Table 3. Summary of roadside slope revegetation practice on 25 National Forests

Technique	Forests using the technique: Number	Forests using the technique: Percent
Seedbed preparation		
Scarifying, rolling with studded rollers, cutting of serrated slopes and terraced slopes, and staged revegetation work during construction	8	36
Seeding and planting		
Broadcast (includes Fertiblast gun)	7	28
Hydroseeder (includes application with hydromulch)	19	60
Seeds applied with dry mulcher	9	40
Contour seeding	1	4
Drilling	1	4
Seeding of shrubs and trees	2	8
Wattling	2	8
Planting of shrubs and trees	3	12
Planting of cuttings	4	4
Mulch		
Wood cellulose (hydromulch)	13	52
Hay or straw, with mulcher	13	48
Hay or straw, manual	1	4
Excelsior	1	4
Wood chips	1	4
Compactors and rollers		
Straw compactors, including studded and brush rollers	4	16
Culti-pactor	1	4
Work crew		
Forest Service	20	88
Contract	10	36

In table 2, notation is made of the method by which the work is done, as "contract" or "Forest Service" crew. Slope revegetation work done by contract is either included in road construction contracts or covered by a special contract. Such work is also included in timber sale contracts which specify that purchasers build the roads. Forest Service crews may be regular road maintenance crews, firefighter or trail crews (available between fires or in off seasons, supervised by a road maintenance foreman experienced in slope revegetation), or roving crews which take equipment to several Ranger Districts or Forests.

Among the conclusions that may be drawn from table 3 is that little seedbed preparation is being done. Wattling is rarely used. Mulching is common, with half the Forests using hydromulch and an equal number using straw and hay mulch. About one-fourth of the Forests broadcast seed, and hydroseeders are used extensively—about three-fourths of the Forests use them. About one-fourth of the Forests plant trees and shrubs, but the amount planted is small. Most of the revegetation work is done by Forest Service crews.

The trend over the past 25 years appears to be toward greater use of equipment and less frequent use of labor, because manpower costs have increased rapidly. As a result, emphasis has shifted to establishment of grass rather than trees and shrubs. This, with the virtual abandonment of wattling, a technique requiring considerable time and hand labor, may have lessened the degree of soil stabilization achieved, as well as impaired the visual effect of forest roadside slopes. Efficient equipment is needed to allow establishment of trees and shrubs to compete in overall cost with establishment of grass.

It is beyond the scope of this report to describe in detail a recommended course of action for roadside slope revegetation. Many helpful discussions of the subject are available (see Additional References).

In the discussion that follows, some of the currently used techniques shown in table 2 are described in greater detail. Some brief comments are made on techniques recommended by the earlier writers on slope revegetation. Reconsideration of these methods may prove helpful, in view of the disappointing results achieved in some current projects. The discussion also includes some recommendations, drawn from the literature or from field observations, that seem worthy of special notice.

Seedbed Preparation

According to W. F. Currier [3/]:

> "A good seedbed is one which will give the best possible moisture condition for germination and plant development. At the same time, it allows the seed to be placed in the soil to a proper depth. Generally, a good seedbed is described as one that is firm under the seed with not over 2 in. of loose top soil."

[3/] Currier, W. F. Methods of seeding. Unpublished report presented at USDA Forest Service Workshop in Critical Area Stabilization, Albuquerque, N. Mexico, April 27-29, 1971.

Kraebel (3) advised treatment of fill slopes by smoothing existing gullies and combing down loose rock, and mechanical anchorage of the surface by a system of contour trenching, embedded wattling, and staking. Juhren 4/ used contour wattling on the Palomar slopes and at Lake Wohlford, with long wheat straw between the rows. The 1937 handbook (7) also recommended mechanical means of stabilization:

> "On roads where the fills have been layered we find that there is an outer surface of from 12 to 18 in. which is relatively loose. Unless this loose material is held in place by some mechanical means such as the brush row or staked wattle, it is quite probable that due to oversaturation of the soil by heavy rains, the force of gravity will cut the slight hold of the loose soil and cause it to slip down over the lower portion of the fill. However, after several years of wettings by annual rains, with the assistance of roots of growing vegetation, this loose 12 to 18 in. of soil should be bound to the finer soil below and the need for mechanical anchorage will be eliminated."

The following is summarized from the "Truck Trail Handbook" of 1940 (6, p. 509-510):

Bank Slopes. Where planting is to be done, the banks must be "stable sloped" or rounded. The slope depends on the soils encountered and the vegetative cover needed to prevent erosion. Cut slopes steeper than the angle of repose of the soil tend to develop overhangs that interfere with revegetation of the banks. If revegetating the slopes in an area is not feasible, however, and if soil characteristics are right, banks may be the most stable when left near vertical, and rounding of the slopes will not be beneficial.

Various methods of slope control are shown in figure 3. In general, heavy mechanical structures such as wattles should be kept at a minimum. Natural seeding with mulch to conserve moisture is preferable.

Limiting factors in vegetation of roadbanks. Subsoil and parent soil material exposed on road cuts of any appreciable depth is relatively unfavorable to plant growth. Planting of cut slopes having unfavorable germinating and growing conditions, such as lack of moisture and exposure of the root systems by soil erosion and frost action, has often resulted in complete failure in establishing vegetative growth. The fill slope is more favorable for establishing vegetation than the cut slope, but is sometimes more subject to rapid erosion.

Mechanical devices to assist establishment of vegetation. Soil instability on banks may be overcome by using mechanical structures such as heavy poles or logs, either staked or wired in place. After these structures are in place, rich top soil is placed between the logs and seeded to grass. Brush wattles are usually superior to piles for holding soil on banks because the larger amount of organic debris tends

4/ Op. cit.

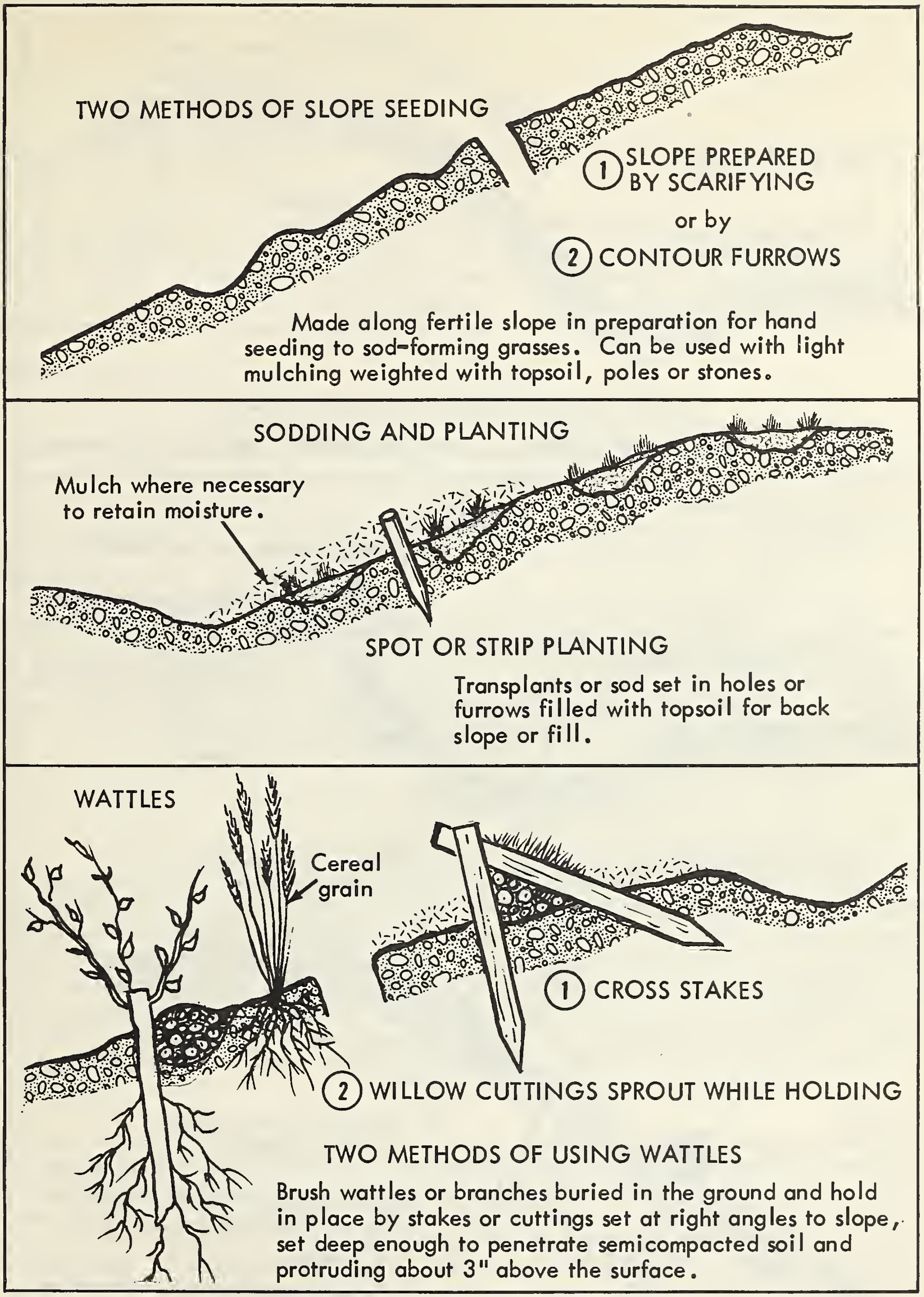
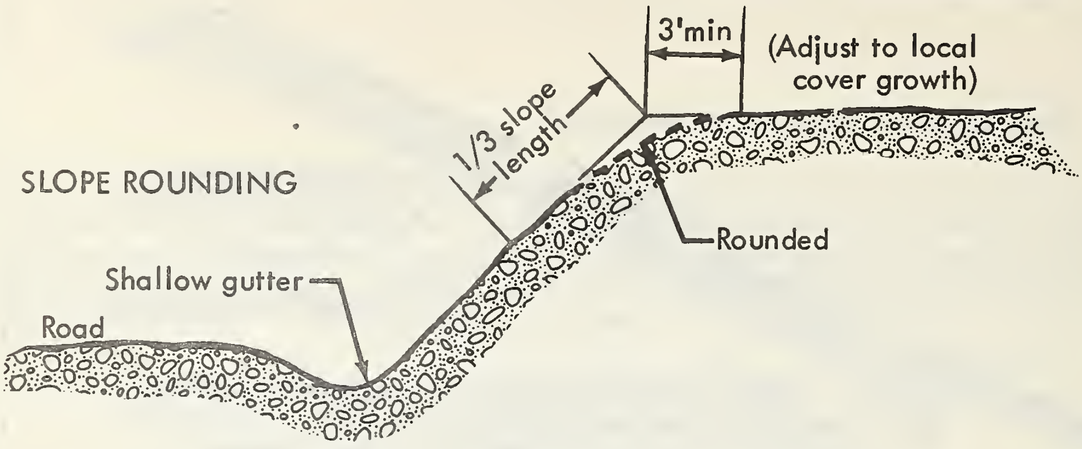


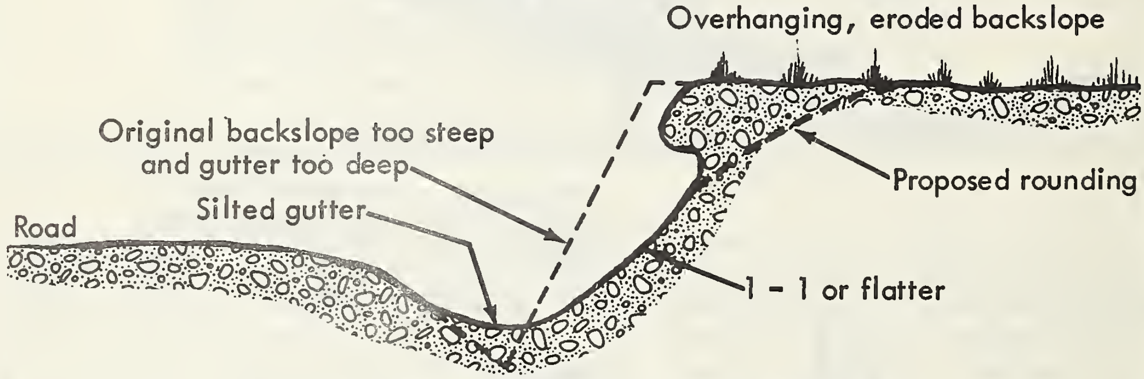
Figure 3. The "Truck Trail Handbook" of 1940 included these drawings of various methods of seedbed preparation and erosion control. These techniques can still be used in difficult areas. Slope rounding is now common Forest Service road construction practice. (Figure 3 continued on next page.)



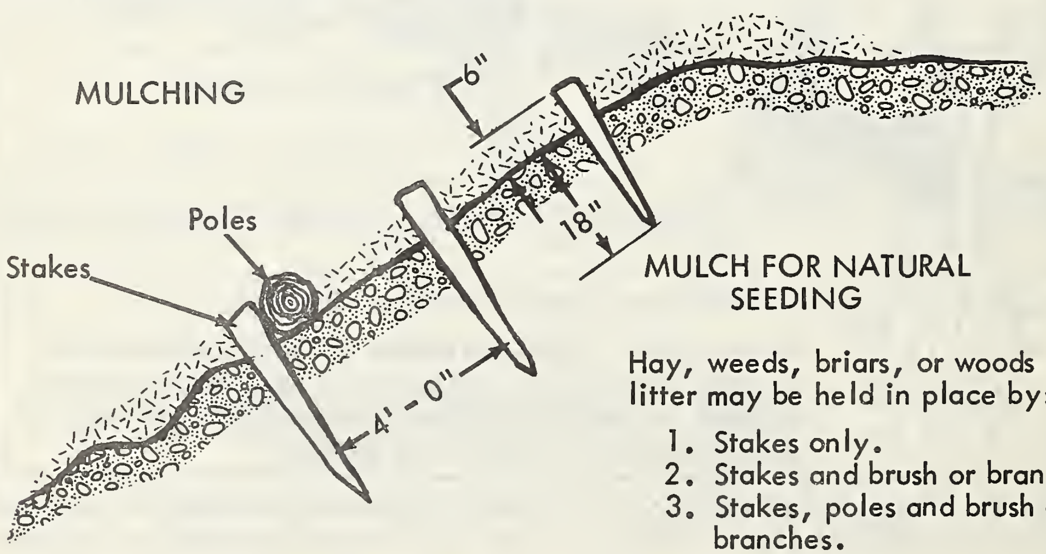
SLOPE ROUNDING ON NEW ROAD BANK

To facilitate planting, stabilize slope and improve appearance.

CUT SLOPE



ELIMINATING OVERHANG ON ERODED EARTH ROADSIDE



MULCH FOR NATURAL SEEDING

Hay, weeds, briars, or woods litter may be held in place by:

1. Stakes only.
2. Stakes and brush or branches.
3. Stakes, poles and brush or branches.

Figure 3. Continued.

to hold moisture and add nutriment. Generally poles and logs and wattles are too expensive for extensive use.

In present practice on the National Forests, seedbed preparation consists of filling rills and gullies, removing some rocks, and smoothing slopes. In most instances there is little or no actual seedbed preparation, particularly on cut slopes. Most contracts have provisions for "site preparation," which usually consists of removing a few large rocks and smoothing rough areas.

Staged Revegetation

There is general agreement that fresh cut and fill slopes should be immediately seeded to take advantage of the loose topsoil. Slopes may need to be treated before construction is complete if there is a seasonal shutdown, or if construction requires a long time. "Staged revegetation" is a method used on the Tennessee Forest Highway (table 2) to lessen soil erosion during construction, for better survival of vegetation, and to allow use of conventional equipment to cover long slopes. Fresh slopes are seeded during the road construction.

A policy of broadcast seeding timber sale roads during construction has been adopted by the Black Hills National Forest. The timber sale inspector broadcast seeds the fresh slope during slack periods of inspection. This allows seed to be applied to loose, aerated soils. Later, after construction is finished, the slopes are seeded, fertilized, and mulched with a hydromulcher (see below, under Mulches).

Terracing

Seedbed preparation may be designed into road cut slopes by various forms of terracing. On the Tennessee Forest Highway, establishment of seedbeds on high, steep cuts is enhanced during excavation of the road by creation of serrated slopes. These consist of 2-ft wide benches cut at each 2-ft contour, forming an overall slope of 1:1. The benches do not allow sheet flows of water to build up much velocity. Each bench catches loose soil, providing a seedbed for vegetation. Eventually enough soil and vegetation are on the benches to give the cut banks a smooth look. The Wallowa-Whitman National Forest in Washington tried this method, using 3-ft benches (5).

On cut slopes, the Carson National Forest, New Mexico, has tested a method developed by Paul Weaver of the Southwestern Region. Terraces are cut to reduce surface flow velocity and erosion, improve penetration of water into soil, and catch fines to enhance revegetation. In this method the terraces are constructed 4-ft wide on 8-ft contours. A 1:1 slope is constructed between the terraces, and the overall slope of the cut bank is $1\frac{1}{2}$:1. Excelsior matting (see Mulches) is placed on the outer 2 ft of the terrace and 2 ft down the slope. There was good success with this method on the small area tested.

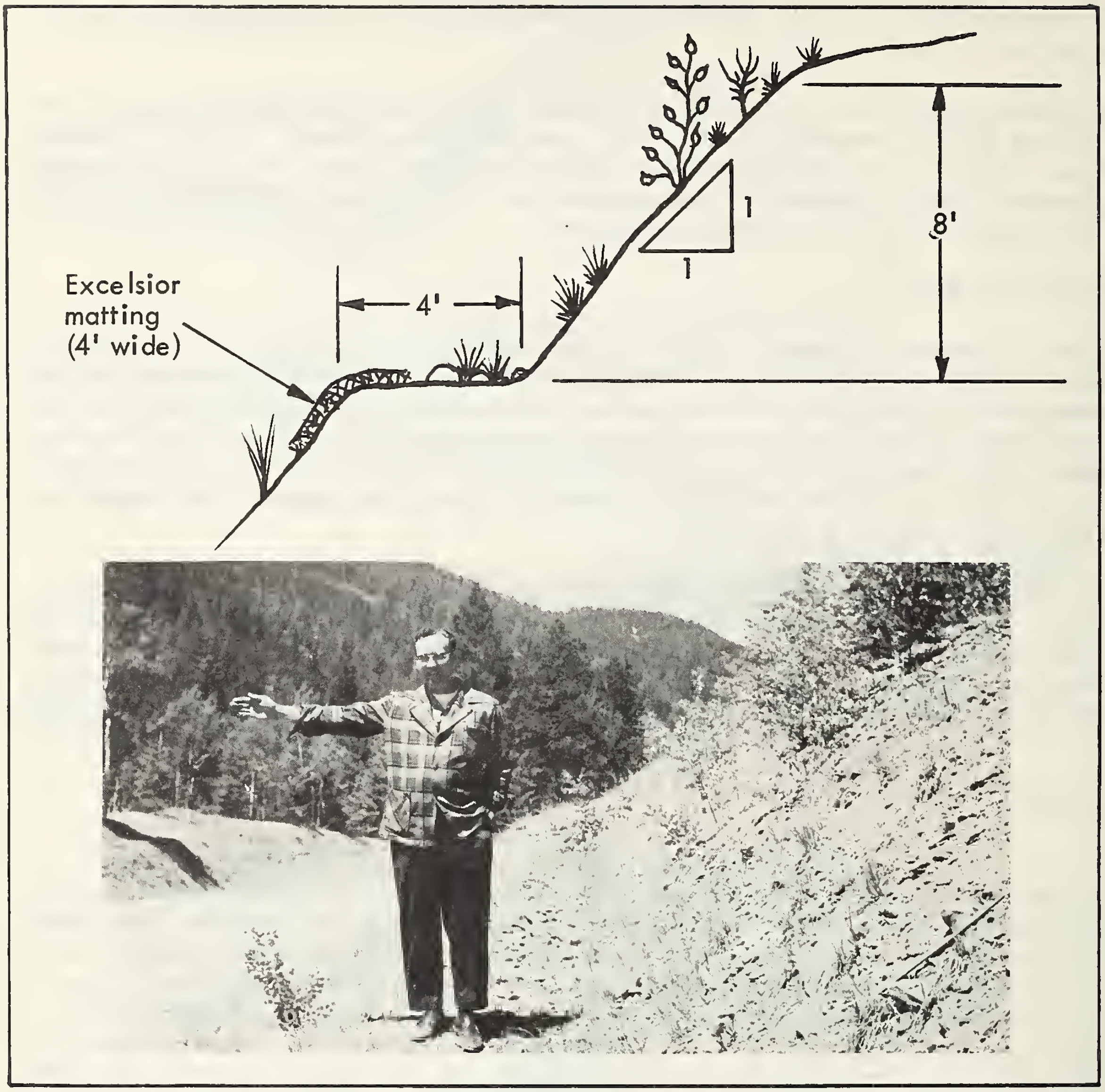


Figure 4. Slope terracing is a useful method of seedbed preparation, employed here on the Carson National Forest.

On the Willamette National Forest, removal of the "root-mat" at the top of the slopes (slope rounding) is practiced. The root-mat permits water to flow and drip onto the slope below, resulting in the cupping out of the soil immediately below the mat. Also, cut slopes are left rough (i.e., not smoothed by grader blade) so they will catch and hold fine soil, seed, and fertilizer. 5/

5/ Jones, Evan E. Road cut and fill stabilization (Willamette National Forest). Unpublished report presented at 24th Annual Meeting, Range Seeding Equipment Committee, Denver, Colo., February 8-9, 1970.

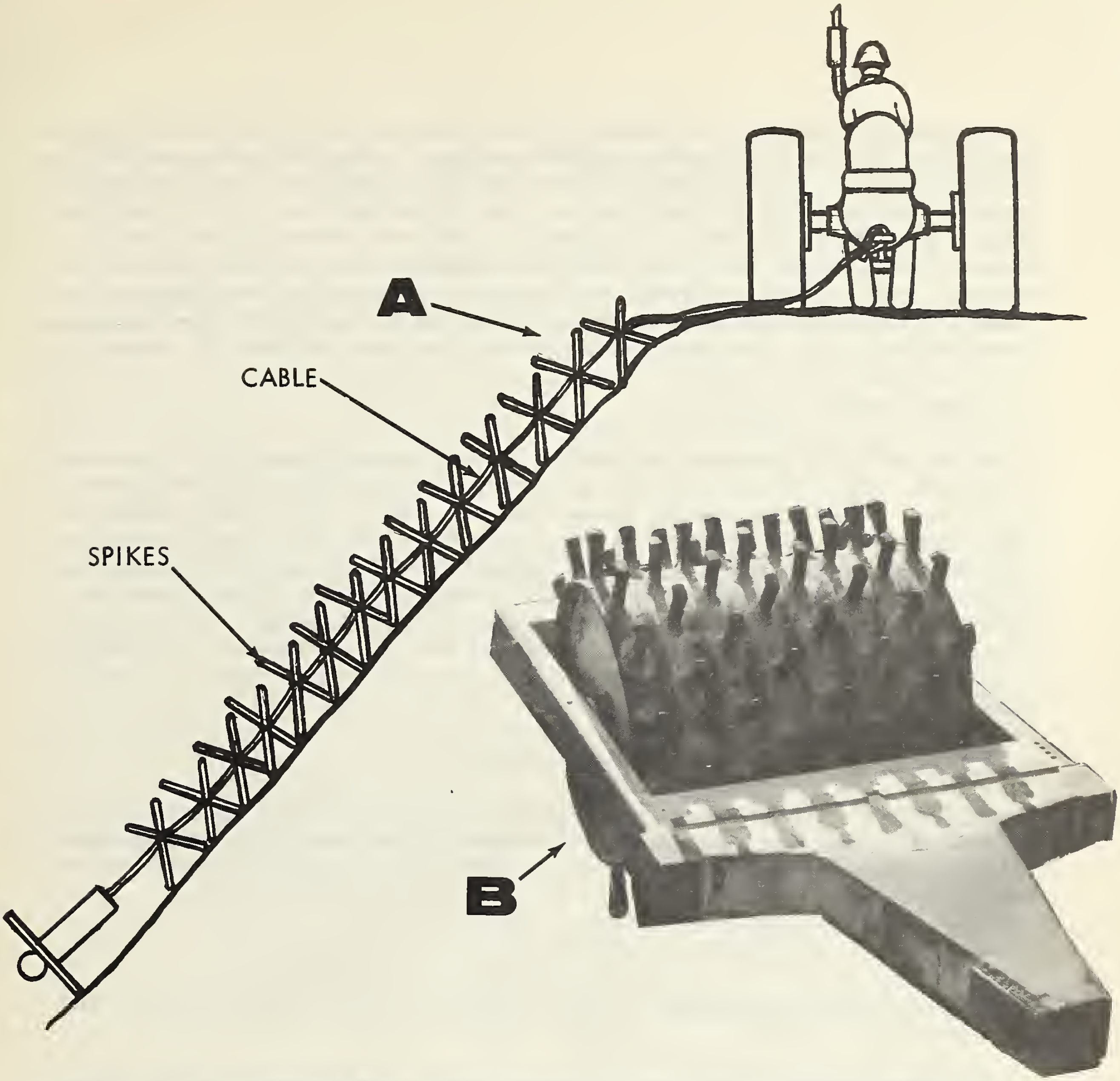


Figure 5. The slope scarifier or clod buster (A) and the sheepsfoot roller (B) are useful in seedbed preparation.

Scarification

In many places a crust forms on the surface of the slopes after they have been exposed to rain and wind for some time. This greatly reduces chances for successful revegetation, because neither seed nor moisture stays on the slope. To eliminate this problem, various methods of scarification—loosening and roughening the surface and aerrating the soil—are used. This practice is analogous to harrowing or disking farmland.

Scarification has generally been limited to the more accessible fill slopes. On the Carson National Forest, the tops of cut slopes are scarified and drilled when the topography is not too steep. There has been much interest in equipment that will

be efficient for scarifying cut slopes. On fill slopes, the chain scarifier (clod buster, fig. 5) and the sheepsfoot roller have been used. The chain scarifier is sometimes difficult to use because of irregularities in slope length and because the chain catches on rocks or other barriers. The sheepsfoot roller is rolled down the slope by gravity and winched up the slope by a side-boom tractor or a truck-mounted crane. This technique has been successful in breaking the crust on the surface and creating small pockets that catch soil and seed. If conditions are unfavorable, however, this method can be undesirable. If the pockets become filled with water, break, and wash out, more erosion occurs than if the slope had been left untouched.

Soil Conditioning

Although soil conditioning is not often a part of seedbed preparation in current practice, it might well be considered. Hottenstein (2) comments that revegetation results from a particular seeding method may be poor in some areas, whereas in other areas the same technique may be successful, and he believes this may be attributed to the pH of the soil. As a general rule for grass, he advises addition of lime when the pH levels are below 6.0. Strongly alkaline soils may need to be buffered with gypsum, organic material, or topsoil before vegetation can be established. Hottenstein also states that fineness of the soil is important to success of vegetation—the range of fines passing a 200 sieve should be between 20 and 80 percent.

Seeding and Planting

The earlier writers comment in some detail on the species and techniques to be used in seeding and planting. Kraebel (3) suggested the "sowing of cereal grains." Juhren 6/ used plantings of trees and shrubs, with some grasses, as has been indicated.

Grasses

Seeding of grasses is described in the "Truck Trail Handbook" of 1940 (6, p. 512) as follows:

> Broadcast seeding. On cut and fill slopes where the soil is fertile and the slopes flat, broadcasting grass seed in season has produced very good results in soil stabilization. Where applicable, this is the simplest and least expensive method. The species used should be the important sod grasses of the locality. The ground must be loosened and prepared. With the exception of clay soils, rolling with a light roller is desirable. Grass seeds should be covered to a depth equal to the diameter of the seed. Soil must contain enough moisture to germinate the seed.

Sod is also mentioned in the handbook as an effective but expensive method of slope erosion control.

Current literature on seeding and planting indicates that species selection should be based on soil conditions, climate, elevation, and exposure. Some of these

6/ Op. cit.

species being planted are shown in figure 6. Climatic conditions include amount and frequency of precipitation, length of frost-free season, temperatures, and wind velocities. Soil conditions include parent material, depth, texture, structure, and pH 7/.

The seeding plan may include replacement of existing undesirable vegetation and the establishment of a temporary "nurse" crop along with the desirable plants. According to Currier, 8/ removal of undesirable vegetation to eliminate competition for nutrients and moisture may be done in one of three ways: cultivate and seed; spray with herbicides and seed; deep-furrow drill. Seeding of nurse crops must be done with care; if the nurse crop is too heavy, the permanent grasses may not develop and all plants may be dead after 2 years. On the other hand, there must be enough annual grasses to significantly reduce soil erosion, which occurs at the highest rate during the first year.

Seed mixtures should be selected to provide quick establishment of vegetation for immediate stabilization of slope surfaces, and later establishment of long-lasting, durable grasses and legumes to stabilize both surfaces and shallow slopes. If grazing animals may be troublesome, grasses not attractive to them should be chosen where possible 9/.

Seeding rate and timing are frequently discussed in the literature. On roadsides, higher seeding rates are needed than on pastures, for example, because the seedbed is of poorer quality. Higher seeding rates are also necessary to compensate for steeper slopes where seeds roll or are blown or washed off (2).

Timing strongly influences results of seeding and planting. In some areas, if seeding is done in late spring or late fall, there may be heavy seedling losses from summer droughts, frost action, and winter kill. It is essential to establish some vegetative cover before the first rainy season or winter to avoid soil and seed losses 10/. Seeding should be scheduled so that moisture and temperature conditions allow germination and enough growth before adverse weather occurs.

7/ Currier, op. cit.

8/ Op. cit.

9/ Peterson, R. Max. Stabilization of cut and fill slopes. Unpublished report presented at the Third Annual Technical Work Planning Conference of Forest Service Soil Scientists, April 5, 1960.

10/ Jones, op. cit.

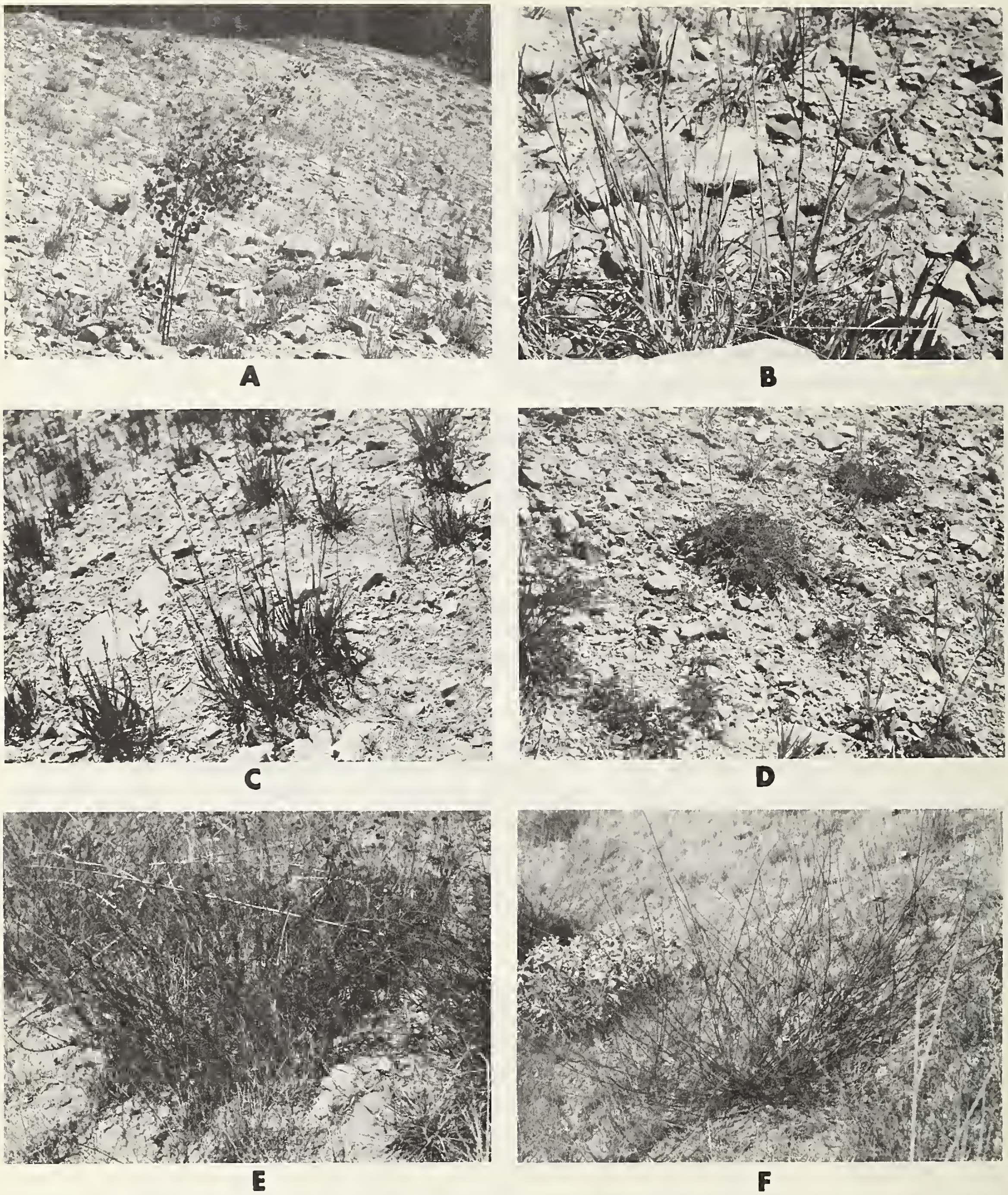


Figure 6. A variety of grasses and other plants are useful on roadside slopes. On the Carson National Forest, a borrow site (A) planted 2 years before, shows transplanted aspen, and seeded crown vetch (upper right corner), smooth brome, and orchard grass. In closer view, orchard grass (B), smooth brome (C), and crown vetch (D) are shown. On the San Bernardino National Forest, buckwheat (E), Spanish brome (F), and intermediate wheatgrass (G) have been successful. The last should be used only above 6,000-ft elevation, however.

G

Figure 6. Continued.

Currier 11/ cites the importance of covering seed, and emphasizes two principles— placing seed on mineral soil, and covering the seed with either soil or mulch:

> "Optimum depth of seeding is roughly proportional to seed size. Small seeded species such as the lovegrasses or timothy should be planted deeper than $\frac{1}{4}$ in., whereas such species as the wheatgrass should be planted to a depth of 1 in."

He found that when seed is applied with the mulch, 60 to 70 percent of the seed is not in contact with mineral soil or is not covered.

Seed should be applied evenly. Too many seeds in an area may result in over-competition for moisture and nutrients, with complete failure. Various seeding methods and equipment are used. As evident from table 2, broadcast seeding is common, and such devices as the Fertiblast gun and the cyclone seeder are available. Hydromulchers are widely used for application of seed with wood cellulose, fertilizers, etc. Drills are the most effective equipment for seeding, but thus far they have not been made adaptable for use on steep roadside slopes. Drills apply seed uniformly and to the desired depth.

In some areas, contour seeding is used to good effect. Contour furrows are formed and planted, usually by hand labor (fig. 7).

11/ *Op. cit.*

Figure 7. This slope on the San Bernardino National Forest hasbeen contour seeded.

Shrubs and Trees

Shrubs and trees may be established by seeding, by transplanting, and by insertion of cuttings. Native shrubs provide excellent soil stabilization because of their generally deep roots and their high capacity to absorb soil moisture. Visually, native shrubs usually blend the roadside slopes into the surroundings better than grasses do. Peterson 12/ points out that shrubs and trees should be used to develop medium and deep root systems to provide mechanical stabilization, and to reduce the quantity of moisture in the soil, lessening the chances of slump failures.

Transplanting was more frequently used in the 1940's than it is now, and the "Truck Trail Handbook" (6, p. 513-514) discussed it as follows:

> Transplants. A skillful, well-trained crew is required to achieve successful transplanting of shrubs and trees. Species of vines and shrubs which are woody and grow vigorously have been most used. Colony-forming vines do well on steep slopes. Plants which reproduce new vegetation by spreading root systems do the best. Success of transplanting is also dependent on adequate moisture, good soil, and planting during the dormant season. Transplanting sapling trees and woody shrubs requires the same care as used in commercial landscaping.

12/ Op. cit.

Other essentials for successful transplanting are:

1. Prompt transplanting before roots dry out.

2. A large pocket hole of top soil.

3. Pruning top growth in proportion to reduction in root system.

4. Planting clump-forming shrubs close together.

5. Mulching the slopes between the plants.

6. Maintenance for about two seasons.

Cuttings. Cuttings or slips offer another alternative of establishing shrubs. They should be planted deep enough so that several buds or branches are in the soil, and must be kept moist until they sprout and are well established. Willows and honeysuckle are examples of species that may be used as cuttings.

> "Plant Species: The selection of plant species for road planting must be governed by the following rules:
>
> 1. Vegetation must not create a fire hazard or nuisance.
>
> 2. The initial planting must establish itself readily with the amount of moisture available from normal precipitation and have rapid and vigorous growth characteristics.
>
> 3. Provision must be made for natural succession of species.
>
> 4. The species must be easily available and easily propagated.
>
> 5. The species should be reasonably attractive for landscaping.
>
> "Native plant species are most desirable. Noxious weeds, hosts, or species that might spread to adjoining lands with injurious effect are to be avoided. Common honeysuckle has been used more than any other plant species in the southeastern states, evergreens are used in New England, baccharis in Southern California, lespedeza in Illinois, and creeping juniper in Colorado. Black locust, with its rapid growth, interlacing root system, and wide range, is extensively used as a soil binder, although the use of trees on roadsides is limited by the encroachment that comes with growth.

"Many varieties including blueberry, snowberry, coralberry, bearberry, blackberry, whortleberry, grape, bittersweet, chokecherry, sumac, and hazlenut can serve well the dual purpose of ground cover and game foods. In the selection and planting of vegetation, the advice and assistance of the nearest Forest Experiment Station should be secured."

The disadvantage of native shrubs is the high cost of establishment, compared to that of grasses. In order to germinate, the seeds of many shrubs must be scarified or stratified. These processes occur naturally in the forest environment, but must be carried out artificially in the nursery or on road slopes. Raising, transporting, and transplanting shrubs require considerable hand labor, as the quotations above indicate. The experience of District Ranger Anselmo Lewis on the Angeles National Forest is of interest here. He advised volunteer Girl Scouts seeking a planting project to broadcast seeds of native trees and shrubs over a few of the most erodible road slopes, and they did so for several years without success. He was about to give up when he found that plants had started to grow, and concluded that if enough seeds and enough time were provided, the seeds will be treated by natural means and will germinate.

The Coeur d'Alene Nursery has been active in developing use of native shrubs. In 1971, with the Colville National Forest, the Nursery planted 400 snowberry and 2,500 dogwood shrubs. Survival was very good. The main problem is that a few years are required to establish enough growth to check surface erosion, as the plants are too far apart when young. Recent experiments have used a cover crop of grass in conjunction with the native shrubs to control surface erosion during the first year or two after construction, when surface erosion is greatest. The Nursery has reported good success with this. 13/

In 1972, with the Colville National Forest and the Soil Conservation Service, the Nursery established study plots on some newly constructed road systems that contained severely erodible road cuts and fills. 14/ The study included the following projects:

1. Various species of grass were sown at different rates.

2. Different rates of fertilization were tested.

3. Two types of mulches—hay and wood fiber—were tested.

13/ Isaacson, John A. Progress Report, native seed and shrub regeneration, 1968-1972. Unpublished report, March 1973, on file at Coeur d'Alene Nursery, Coeur d'Alene, Idaho.

14/ Sears, D.E., and Lee Mason. Roadside revegetation program. (Progress Report, 1973; study conducted by Coeur d'Alene National Forestry Nursery and supported by USDA Soil Conservation Service, Colville National Forest, Engineering Branch). Unpublished report on file at Coeur d'Alene Nursery, Coeur d'Alene, Idaho.

4. Direct seeding of various species of native shrubs was tested.

5. One severe, sandy road cut was planted with Volga wild rye culms supplied by the Soil Conservation Service.

Extreme weather followed the seeding and planting. This included heavy rain in the late fall. Snow cover was below average in the winter and there were drought conditions in the spring.

Results of the study indicate:

1. There was good establishment of the grasses, particularly the native grasses, seeded from the hay mulch. It is hoped that the native grasses will act only as a cover crop until the drought-tolerant species can become established and moisture stress removes the undesirable species. Germination was as follows:

Hard fescue	85%
Siberian wheatgrass	85%
Thickspike wheatgrass	88%
Sheep fescue	80%
Indian ricegrass	11%

More than 20 pounds per acre of seed results in rapid depletion of available moisture.

2. High fertilization at time of sowing and periodic followup have resulted in vigorous growth.

3. Hay mulch was more successful than the wood fiber.

4. Direct seedings of shrubs were not very successful.

5. The survival success of Volga wild rye was outstanding.

During the fall of 1973, the Coeur d'Alene Nursery shipped 261,945,000 shrubs to the Northern, Intermountain, and Pacific Northwest Regions and to seven other governmental agencies [personal communications].

Promoting Germination and Growth

At or after the time of seeding and planting, a variety of materials may be used to promote germination and growth. These include topsoil, fertilizers, and other chemical additives and mulches.

In the early literature, straw mulches are frequently mentioned, as by Juhren [15/].

[15/] Op. cit.

The 1937 handbook (7) recommends hay mulch and grass, and forest litter mulch. The "Truck Trail Handbook" (6, p. 510-512) comments on topsoil and mulching as follows:

> "The method of placing rich top soil on road slopes and seeding to herbaceous cover has been tried extensively in different parts of the country . . . Repeated failures on the same bank have demonstrated that while top soil dressing is excellent to assist vegetation establishment on road banks, it is not in itself a stabilization measure and rather should be considered a supplement to proven stabilization methods.
>
> ". . . Besides protecting exposed soil from all forms of climatic stress, mulches produce ameliorating effects upon the soil, both chemical and physical. They prevent drying out of the soil, maintain a more nearly uniform and favorable growing temperature, and, as they decompose, add to the soil organic material and plant nutrients . . . In general, light applications of mulch are more desirable than are heavy applications. Too heavy applications prevent free circulation of the air which may lead to composting and actually kill the seed, as well as prevent seedling growth."

Current practice makes use of fertilizers and additives, and mulching is common.

Fertilizers

Roadside slopes consist of subsoil materials which are nearly always low in plant nutrients. Most of these soils need addition of nutrients to support vegetation. Nitrogen is virtually absent in most subsoils because they are low in organic content. Phosphorus is also usually low (2). Nitrogen is essential for the growth and establishment of vegetation on all roadside soils. Phosphorus is beneficial to stimulate early growth and root formation. Potassium is also beneficial to the establishment of grasses. Fertilizer selection and application rates should be based on soil test and the type of vegetation being seeded or planted. Some fertilizers commonly used are 16(N)-20(P)-0(K), 30-10-0, and 20-10-5.

Applying fertilizer for one or more consecutive years is essential to prevent degeneration of the vegetation that has been established. Nitrogen may be lost through leaching, but phosphorus and potassium in plants are returned to the soil for reuse from season to season. Thus the Willamette National Forest uses urea (45-0-0), which is high in nitrogen but does not contain phosphorus or potassium, applied at the rate of 100 to 200 lb per acre for refertilizing 16/.

During visits to several forests, construction and maintenance personnel commented on the importance of returning the year after planting with an application of

16/ Jones, op. cit.

fertilizer. This is seldom done because of the immediate need of seeding non-vegetated slopes and problem areas which require all the funds and manpower. "Fertilizer can be applied annually over a 20-year period on poor soils at 1/5 to 1/10 the initial cost of top soil." (2) On projects requiring mulch, fertilizer application can amount to only 5 to 10 percent of the total costs.

Chemical Additives

Various compounds are available that are dissolved in water for application. The manufacturers claim that these additives make hydromulch and seeds adhere to steep banks, help stabilize soils by binding soil particles together, reduce evaporation, allow soil to accept moisture readily, promote germination, or reduce fertilizer leaching. Some examples of additives are Aquatain, Super Verdyol, and Sta-Soil. The success of these additives has ranged from good to poor on the several Forests which have tried them (table 2).

Mulches

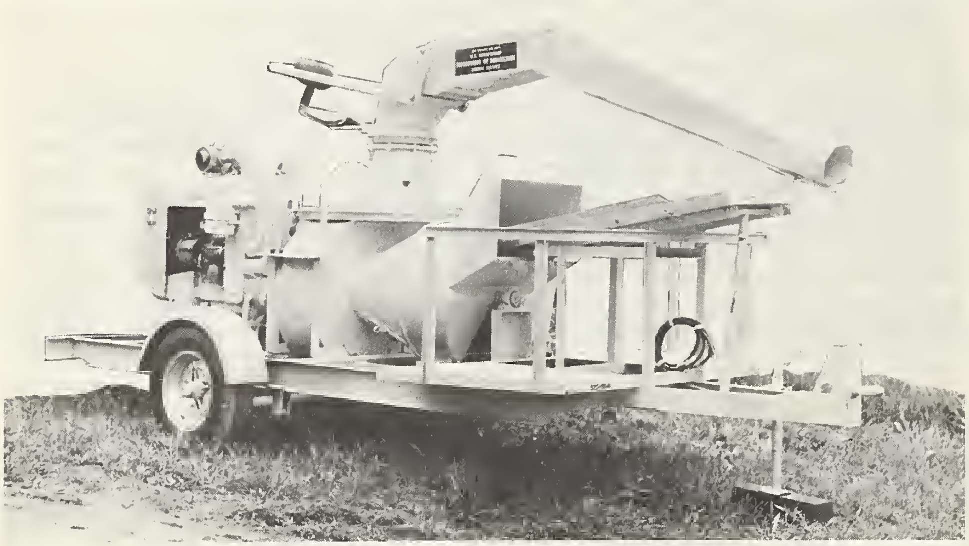
Mulches provide temporary stabilization of surface soils until a cover of vegetation is established. They protect the soil surface against water and wind erosion, and reduce surface evaporation, permit penetration of rainwater into soil, and help prevent crusting of the surface. Mulches may also hold seed in place, and protect seed from rapid temperature change and from direct sunlight—but these objectives are better accomplished with soil when possible. Relatively level areas should not usually require mulches. The cost of mulch material and its application is high compared to seed and fertilizer. Thus mulches should be used only where they are needed.

As noted earlier, when mulches are blown on with the seed, much of the seed is suspended in the mulch with no mineral soil contact, and survival is reduced by this amount. For best results the seed should be covered with soil before the application of mulch.

Although many different types of material may be used for mulch, three types are most common on road slopes: straw, hay, and wood cellulose. Straw mulch is usually blown on by a mulching machine of the air-blower type, which may apply seed and fertilizer at the same time. Often water or an asphalt emulsion is sprayed out through the nozzle with the mixture. The asphalt adds weight, and sticks the straw particles together to reduce the loss of the straw mulch from winds. On three of the Forests the straw is punched in with a steel-studded roller (fig. 8). This holds the straw in place, and the stems act as a reinforcement to the soil. About 2 to 4 tons of straw per acre are usually applied.

Hay is applied in the same manner as straw mulch. The use of hay instead of straw makes use of the seeds contained in the hay; also, because hay is not as slippery as straw, it is supposed to adhere to the slopes better. Tests on the Caribou National Forest, Cache National Forest, and Wasatch National Forest in 1967 showed no difference in the results of hay as opposed to straw.

A



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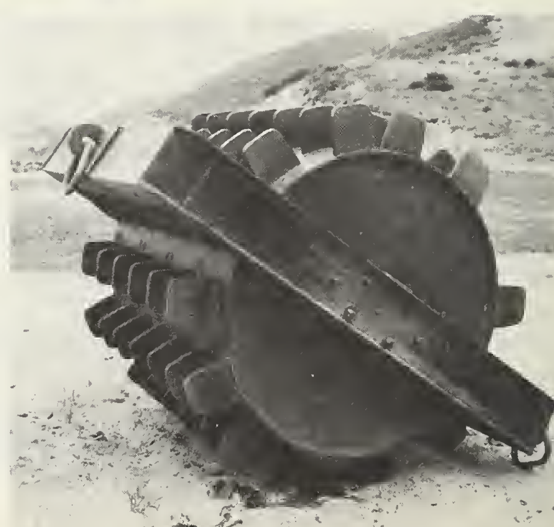

Figure 8. Mulching equipment currently in use on National Forests include (A) the hydromulcher shown here on the Black Hills National Forest; (B) the hay or straw mulcher, in use on the Gifford Pinchot National Forest; and (C) the straw compactor, in use on the Angeles National Forest.

Wood cellulose mulch is a manufactured material, applied with water as the conveyor, using equipment called a hydromulcher or hydroseeder (fig. 8). Wood cellulose mulch is usually applied at 1,000 lb per acre. Seed and fertilizer or other additives (fig. 9) are usually mixed and applied at the same time as the mulch.

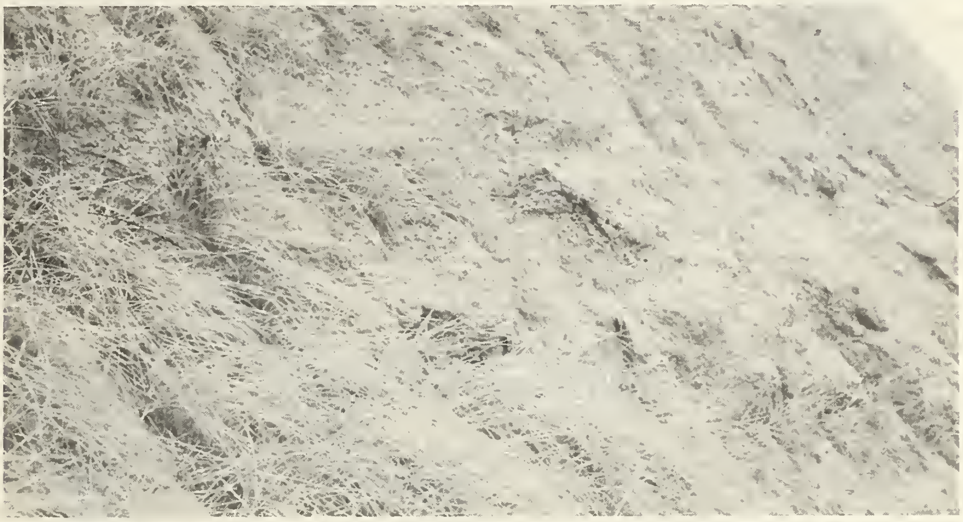

Figure 9. Here a decomposed granite cut slope on the Cleveland National Forest has been treated with hydromulch containing Aquatain.

Another form of mulch is excelsior, applied with conventional mulch spreaders. It has been used in the Southwestern Region, and by the New Mexico Highway Department with success. Details of performance of commonly used mulching equipment are given in table 4.

Excelsior also comes in blankets or mats that may be rolled onto the slope. This has been very effective where high winds blow conventional mulches off the slopes. It has also been successful on steep cut banks, as rock and soil are held in place from raveling until vegetation has had a chance to become established. Several test sections on the Carson National Forest have verified this.

Proper Road Maintenance Procedures

Several writers mention the importance of care in road maintenance to avoid destruction of plants on revegetated slopes. Juhren 17/ reported damage from carelessness, as described earlier. More recently, Jones 18/ comments on seedbeds destroyed by road maintenance, noting that toes of cut slopes should not be undercut when ditches are cleaned, and waste soil and rock from road maintenance should not be dumped on revegetated slopes, but in specific disposal areas.

17/ Op. cit.

18/ Op. cit.

PROSPECTS FOR FUTURE DEVELOPMENT

In view of the emphasis on use of equipment rather than hand labor, future progress in the area of slope revegetation will probably take the form of development of equipment suitable for work on steep slopes. Several suggestions along such lines were made by Forest Service field and research personnel. Scarifiers mounted on equipment that can be extended up and down for seedbed preparation on cut and fill slopes was suggested most often. Equipment for transplanting trees and shrubs on steep road slopes without disturbing the slopes or existing vegetation was also requested. Hydraulic cranes such as those used for telephone line and bridge inspection might be adapted for both these purposes (fig. 10). A scarifier attachment would have to be designed for this use.

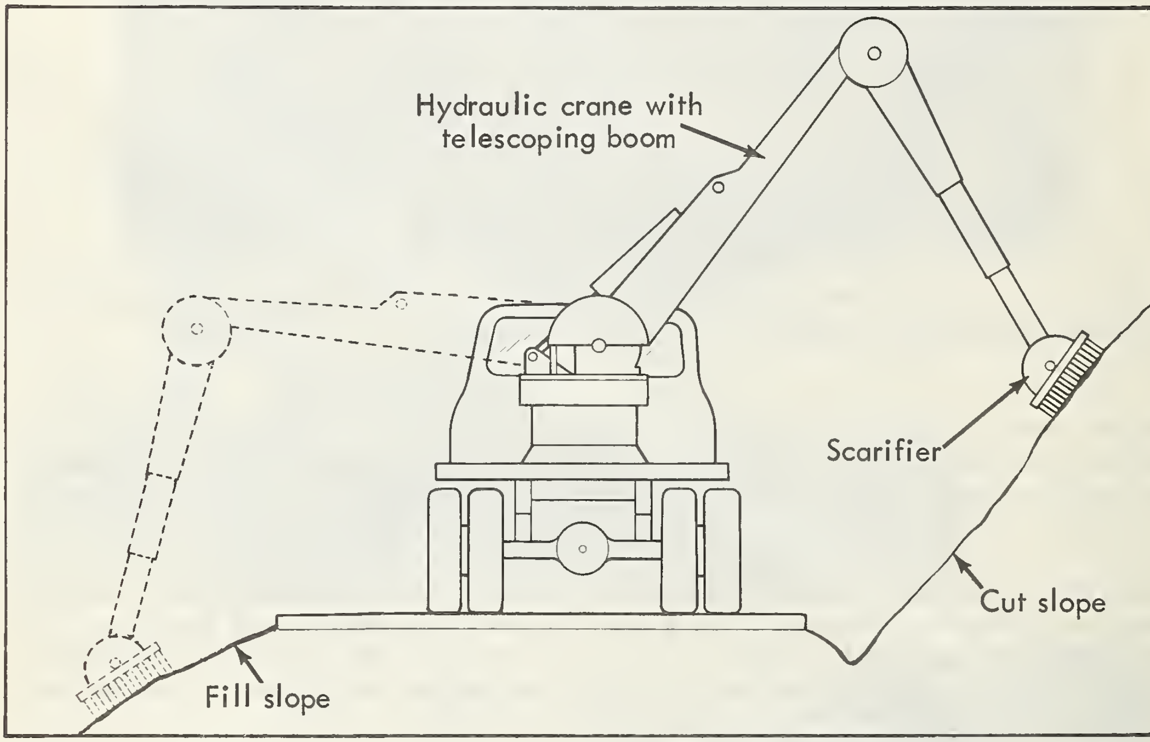

Figure 10. Equipment for scarifying and planting steep cut slopes might take the form shown in these sketches. The crane with boom is commercially available. Approximate cost for this equipment, truck included, is $50,000.

A seed drill that can be operated on steep slopes was another request. Equipment developed under Equipment Development and Test project 2062 (fig. 11) may answer this need (4). Such equipment would be designed to create minimum impact on the slope and avoid causing or intensifying erosion problems.

Another concept that should be investigated is the slant-wheel tractor. Here, the axle of the tractor assumes the approximate slope of the terrain while the wheels remain vertical (fig. 12). Such tractors as this that are presently available can only work on moderate slopes. The concept would have to be expanded for steep slopes and a seed drill for this type of tractor would also have to be developed.

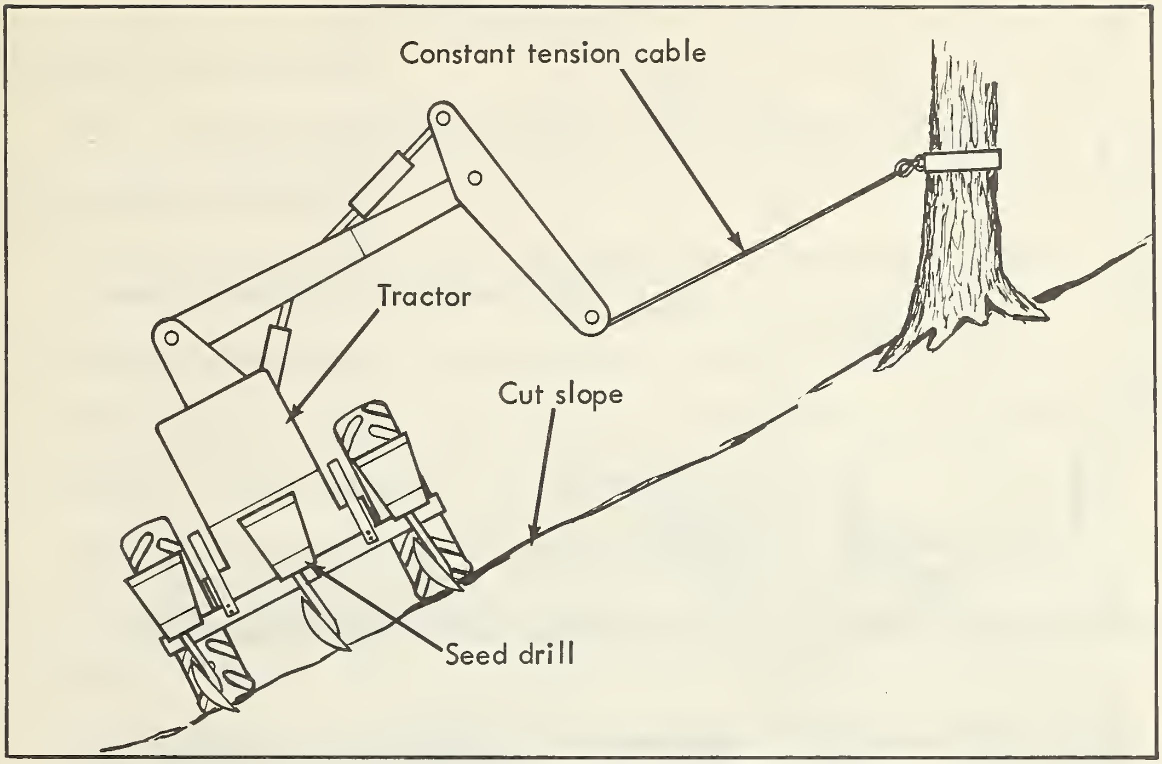

Figure 11. A proposed seed drill for planting slopes.

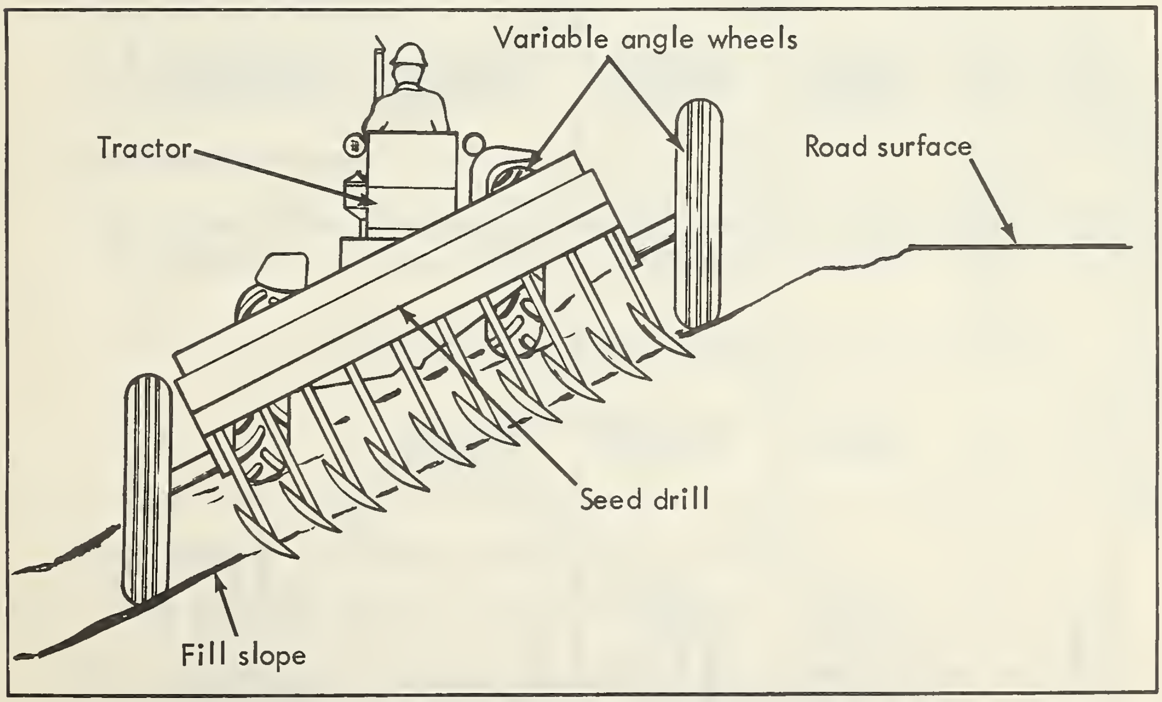

Figure 12. The slant-wheel tractor shown on the fill slope is now commercially available for use on moderate slopes.

Table 4. Performance of some available mulching machines (1)

Hydroseeders and hydromulchers					Hay or straw mulchers		
Manufacturer and model	Maximum throw	Load seeding	Working capacity	Emptying time	Manufacturer and model	Capacity	Reach, in calm air
	Ft	Acres (Max.)	Gal	Min		Tons/hr	Ft
Reinco					Finn		
HSJ-5WX	80	1+	500		Finn	10	80
HSJ-10WX	150	3	1000	12-18	Bantam	2-3	
HSJ-15FX	175	5	1500	12-20			
Finn					Reinco		
Bantam 5	80	2	500	12	M60F6	9	90
Bantam 8	80	3	800	19	M60W	8	85
Super 1300	200	4	1300	9	TM7-30	4	60
Titan	200		2500	15			
Toro Evco							
U5	100	2/3	500	5-10			
U10	150	1+	1000	5-10			
U15	200	2	1500	10-15			
U30	200	4	3000	15-20			
Bowie							
500 Victor			500				
1000 Windsor			1000				
1500 Senior		3+	1500	15			
1500 Imperial		3+	1500	15			
2500 Imperial	200	3+	2500	15			

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